Fuzzy Inference Network and Search Strategy using Neural Logic Network

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ABSTRACT

Fuzzy logic ignores some information in the reasoning process. Neural networks are powerful tools for the pattern processing, but, not appropriate for the logical reasoning. To model human knowledge, besides pattern processing capability, the logical reasoning capability is equally important. Another new neural network called neural logic network is able to do the logical reasoning. Because the fuzzy inference is a fuzzy logical reasoning, we construct fuzzy inference network based on the neural logic network, extending the existing rule- inference network. And the traditional propagation rule is modified.

신경논리망을 이용한 퍼지추론 네트워크와 탐색전략

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요 약

퍼지 논리의 추론과정에서 일부의 정보가 무시되어 적절하지 못한 추론 결과를 초래할 수 있다. 한편 신경망은 패턴 처리에는 적합하지만 인간의 지식을 모델링하기 위해서 필요한 논리적인 추론에는 부적합하다. 그러나 신경망의 변형인 신경 논리망을 이용하면 논리적인 추론이 가능하다. 따라서 본 논문에서는 기존의 신경논리망을 기반으로 하는 추론네트워크를 확장하여 퍼지 추론 네트워크를 구성한다. 그리고 기존의 추론 네트워크에서 사용되는 전파규칙을 보완하여 적용한다. 퍼지 추론 네트워크상에서 퍼지 규칙의 실행부에 해당하는 명제의 믿음 값을 결정하기 위해서는 추론하고자 하는 명제에 연결된 노드들을 탐색해야 한다.

1. Introduction

Expert system has been the most successful one among the application systems based on the research results in the artificial intelligence area. The main problem area in the expert system is knowledge acquisition, i.e., it is very time-consuming to acquire experts knowledge. It is also very difficult to transform all the acquired knowledge to the rule of "IF⋯THEN" form [1,5,7,11]. In order to resolve these problems, machine learning is widely being studied for developing the self- learning system. Neural network and genetic algorithm are in the category of machine learning. Therefore, a hybrid system, which combines the expert system with genetic algorithm and neural network, is considered as the new methodology for the next generation artificial intelligence system [1,2,4,5]. Regarding this, Quinlan [13] proposed an automatic rule generation method using decision tree. Gallant established a basis for coupling neural network and expert system [5,8]. According to Gallant, knowledge base is constructed by using neutral network, and the knowledge acquisition problem can be solved by learning knowledge base using efficient learning algorithms such as pocket algorithm [5]. However, the logical reasoning capability as well as the pattern processing capability is required to model human knowledge. In this reason, there has been

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a research activity which enables the logical reasoning by using reasoning network constructed by neural logic network [1] which is a modified neural network.

On the other hand, the expert system which introduces fuzzy logic in order to process uncertainties is called fuzzy expert system. The fuzzy expert system, however, has a potential problem which may lead to inappropriate results due to the ignorance of some information by applying fuzzy logic in reasoning process in addition to the knowledge acquisition problem. In order to overcome these problems, We construct fuzzy inference network by extending the concept of reasoning network in this paper. In the fuzzy inference network, the propositions which form fuzzy rules are represented by nodes. And these nodes have the truth values representing the belief values of each proposition. The logical operators between propositions of rules are represented by links. In this paper, the propagation rule [2] used in the existing rule-inference network is modified and then applied.

In the fuzzy inference network, to determine the truth values of propositions in the execution part of fuzzy rules, the nodes linked with the propositions are to be searched for. In order to do this, we conduct a simulation to evaluate the search costs for search sequentially all the nodes along the links and for search by means of priorities given to the links.

2. Neural Logic Network

Neural logic network is a basis for the effective modeling of three-valued boolean logic using the existing neural network, and it may be extended further to perform probabilistic or fuzzy logic. While the existing boolean logic was developed based on the two values, "TRUE" and "FALSE", the three-valued boolean logic additionally includes "UNKNOWN" [1,2,4]. Neural logic network is represented by finite directed graphs using nodes and links. Sequence pair(x, y) which corresponds to weighting factor is assigned to every link. Fig.1 shows an example of neural logic network.
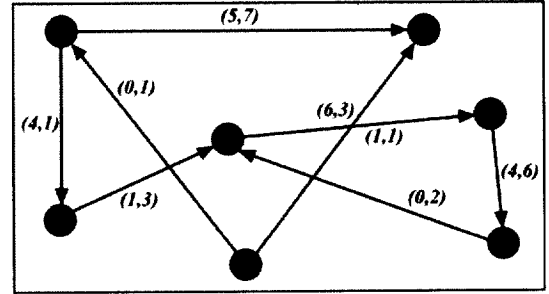
Fig. 1. Neural Logic Network

Each node above has one of the following three activation values

(1,0) for "TRUE"
(0,1) for "FALSE"
(1,1) for "UNKNOWN"

The following propagation rule is used to determine the activation value of P node in Fig. 2[1]. The nodes linked with node P are $\{Q_1, Q_2, \cdots, Q_n\}$, Node value of Q_i is (a_i, b_i) and the weighting value of a link between P and Q_i is (x_i, y_i).

Step 1 : Compute $\alpha = \Sigma a_i x_i$ and $\beta = \Sigma b_i y_i$

Step 2 : Activation value of node P is calculated as

(1,0), for $\alpha - \beta \geq 1$
(0,1), for $\alpha - \beta \leq -1$
(0,0), otherwise.

Using the neural logic network, logical operation can be represented.
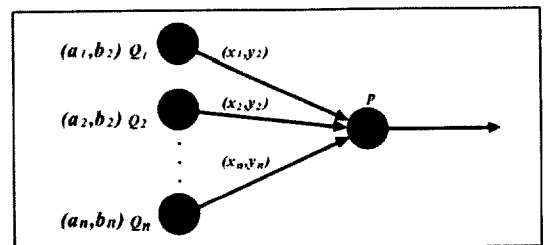
Fig. 2. propagation rule for Neural Logic Network

Figs 3 to 6 show "AND", "OR", "NOT", and "IF …THEN" operations for three valued logic with two inputs.
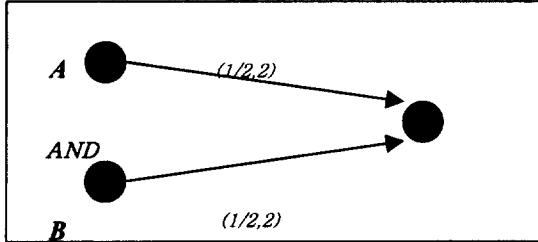
Fig. 3. A AND B
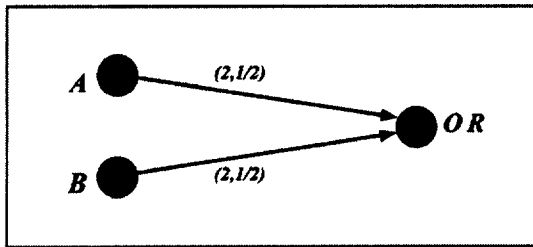
Fig. 4. A OR B
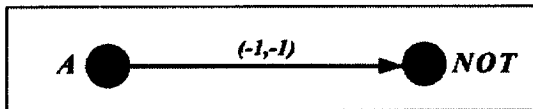
Fig. 5. NOT A
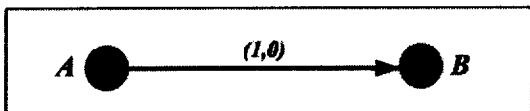
Fig. 6. IF A THEN B

Using the above definitions of logic operations, we can easily represent the rules including arbitrary logical operators using neural logic network. An example is shown below.

IF (A AND B) OR (NOT C) THEN D

Each node in the network corresponds to a proposition or a logical operator in the rule, and the reasoning process can be represented by neural logic network consisting of nodes and links.
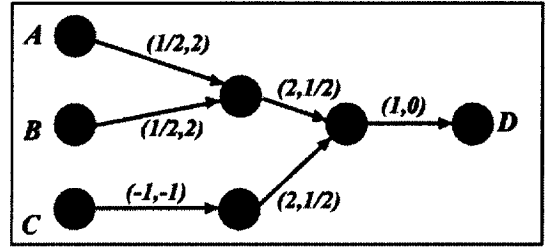
Fig. 7. Representation of a rule using Neural Logic Network

3. Construction of Fuzzy Inference Network

3.1 Construction of Nodes

Fuzzy inference network consists of input node (I), hidden node (H) and output node (O) as shown in Fig. 8 [2].
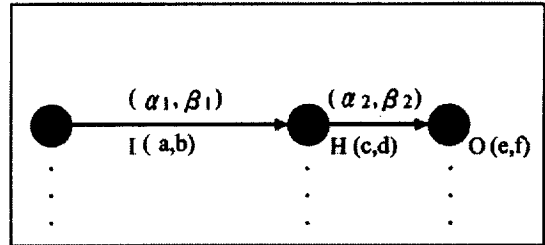
Fig. 8. Construction of fuzzy Inference Network

Each input node corresponds to a proposition in the condition part under the fuzzy rule. Node values for the input nodes are given by knowledge engineer in the form of sequence pair (a, b) which consists of non-negative real numbers. "a" and "b" are quantitative expectations for the proposition related to the node to be "TRUE" and "FALSE", respectively. For instance, if 70 and 20 out of 100 experts replied "TRUE" and "FALSE" to a proposition, respectively, and 10 experts did not know the answer, (a, b) becomes (0.7, 0.2).

Hidden node represents a logical operation and its values are (c, d). These node values are non-negative real numbers and determined by the propagation rule to be discussed in section 3.4.

Each output node represents execution part of

a fuzzy rule. The node values (e, f) are non-negative real numbers and determined by input and output node values and weighting factors between nodes. There output node values e and f are the basis to decide whether the corresponding execution part in adopted or not. IF "l-e-f" is large, the decision cant be node.

Nodes are connected by links, and weighting factors (α, β) are given to links. α and β may be zero, negative or positive real numbers depending on the logical operation and the number of propositions in the conditional part of the fuzzy rule. The method to determine weighting factors is described in the next section.

3.2 Link and weighting factor

In the fuzzy inference network, each node is connected by links, and the weighting factors given to links are determined by the logical operations and the number of input nodes.

(1) "AND" operator

In case that the conditional part of the fuzzy rule is "C_1, AND C_2 AND ... AND C_n", the weighting factor (α, β) is (1/n,n) as shown in Fig. 9.
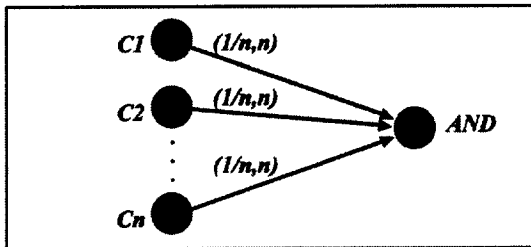
Fig. 9. "AND" operator and weighting factor.

(2) "OR" operator

In case that the conditional part of the fuzzy rule is "C_1 OR C_2 OR ... OR C_n", the weighting factor (α, β) is (n,1/n,) as shown in Fig. 10.

(3) "NOT" operator

For "NOT" operator, the weighting factor (α, β) is (-1,-1) as shown in Fig. 11.
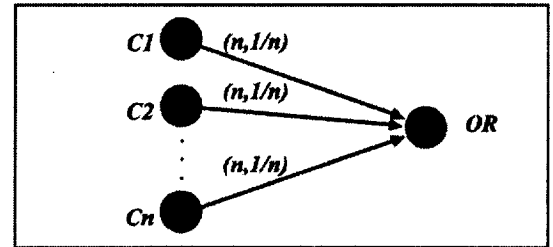
Fig. 10. "OR" operator and weighting factor.
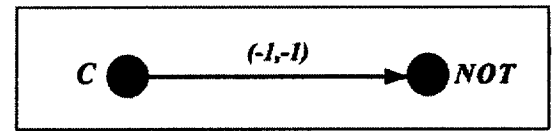
Fig. 11. "NOT" operator and weighting factor.

(4) "IF ... THEN" operator

For "IF ... THEN.." operator, the weighting factor (α, β) is (1,0) as shown in Fig. 12.
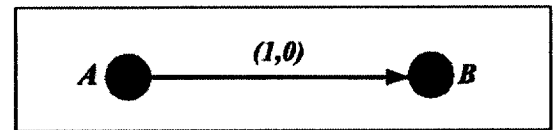
Fig. 12. "IF ... THEN" operator and weighting factor

3.3 An Example of Fuzzy Inference Network

Any kind of fuzzy rules in the form of "IF ... THEN" can be represented by the method of fuzzy inference network explained in sections 3.1 and 3.2. For example, the fuzzy rules below can be represented by fuzzy inference network in Fig. 13.

Fig. 13. An Example of Fuzzy Inference Network

IF a(0.8,0.2) AND b(0.3,0.7) THEN e
IF c(0.6,0.4) AND NOT d(0.9,0.1) THEN e

3.4 Propagation Rule

In a fuzzy inference network, propagation rules are needed to determine node values which are propagated from one node to another node. In this paper, the propagation rules used in the existing inference networks are modified and then applied to the fuzzy inference network.

The propagation rule to determine the node value of an arbitrary node H in Fig. 14 is described below.
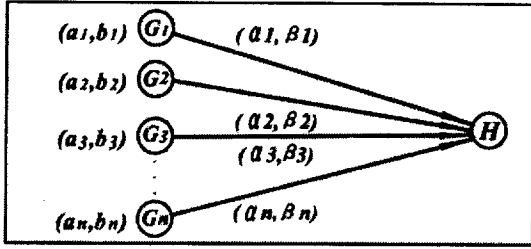
Fig. 14. Propagation of Node Values in Fuzzy Inference Network

(Step 1) For input nodes, unknown, true, and false are calculated as follows :

$$\text{unknown} = \sum_{1 \le i \le n} 1 - a_i - b_i$$

$$\text{true} = \sum_{1 \le i \le n} a_i \alpha$$

$$\text{false} = \sum_{1 \le i \le n} b_i \beta$$

(Step 2) Node value (a_h, b_h) of node H is calculated as follows :

a_h = true / (true + false unknown)

b_h = false / (true + false unknown).

(Step 3) Critical value θ_h is determined as follows:

$$\theta_h = (I_{max} + I_{min})/2$$

where $I_{max} = (\bigvee_{1 \le i \le n} a_i) \vee (\bigvee_{1 \le i \le n} b_i)$

$I_{min} = (\bigwedge_{1 \le i \le n} a_i) \wedge (\bigwedge_{1 \le i \le n} b_i)$

(Step 4) IF a_h, - $b_h \ge Q_h$ THEN a_h=1, b_h=0 ELSE a_h and b_h remain the same value in step 2.

4. Search Strategy in Fuzzy Inference Network.

4.1 Sequential Search

By sequential search, in order to determine the belief value of the final proposition in a fuzzy inference network, all nodes connected with the proposition node are searched sequentially. For example, assume that we need to determine the belief value of a proposition Q, when the following fuzzy rules are given:

IF a (0.9,0.1) AND b (0.5,0.5) THEN Q
IF c (0.7,0.2) AND d (0.4,0.6) THEN Q
IF e (0.2,0.8) AND NOT f (0.7,0.3) THEN Q
IF g (0.8,0.2) AND h (0.6,0.4) THEN C
IF i (0.9,0.1) AND j (0.8,0.2) THEN C
IF k (0.5,0.4) AND l (0.6,0.3) THEN C

Above fuzzy rules construct the fuzzy inference network in Fig. 15.
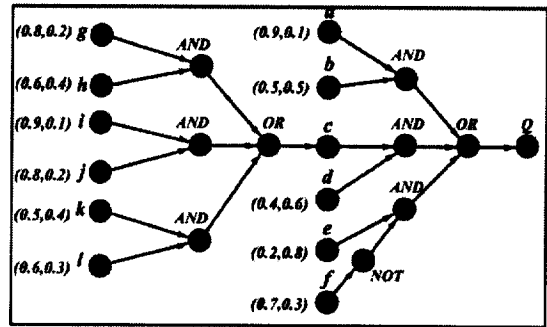
Fig. 15. Construction of Fuzzy Inference Network

To determine the belief value of node Q, it is necessary to know the belief values of input nodes connected with node Q. The input node of node Q is "OR" operator node. The belief value of the "OR" node is again determined by the input nodes connected with the "OR" node. Three "AND" nodes are

connected with the "OR" node and sequential search is performed. If the belief value of a "AND" node is determined to be true, search is no more performed. Then the belief values of "OR" and Q nodes become (1,0) which means true.

When the search is performed for the first "AND" node, this node has two proposition nodes a and b. Using the fuzzy inference network shown in Fig. 16, the belief value of the first "AND" node can be determined by the propagation rule explained in section 3.4.
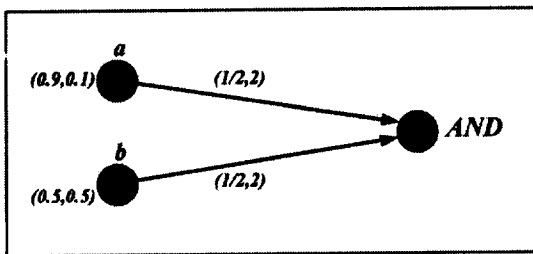
Fig. 16. "AND" node in Fuzzy Inference Network

Following the same procedure, the other two "AND" nodes are searched for. When belief values of the three "AND" nodes are determined, belief values of Q node and "OR" node connected with the Q node are determined, and then the search for the fuzzy inference network is finished.
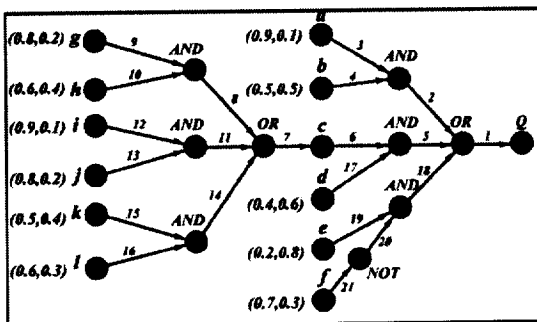
Fig. 17. Sequential Search of Inference Network

4.2 Search by Priorities

In search by means of priority, search priority is assigned to each link and then the search is performed by the priority. The method to decide priority depends on logical operators of the connected nodes.

(1) "OR" node

Higher priority is given to the link connected with the node which contributes more to make the belief value of the node true.

(2) "AND" node

High priority is given to the link connected with the node which contributes more to make the belief value of the node false.

The reason of the above "high priority" policy is that, when a node out of the input nodes is true [false] in case of "OR" ["AND"] node, search for the other nodes is no more necessary. For example, assume that search of a fuzzy inference network is performed 100 times to determine the belief value of node Q. There are 3 "AND" nodes as input nodes of "OR" node which is connected with node Q. Assume that the belief value of node Q is determined by the belief value of the first [second, third] node 15[80, 5] times out of 100 times. Then the second "AND" node will have the highest priority because the probability for second "AND" node to determine the belief value of node Q is the highest.

The first "AND" node will have the next priority. Therefore, the third "AND" node has the lowest priority. Fig. 18 shows an example of search by
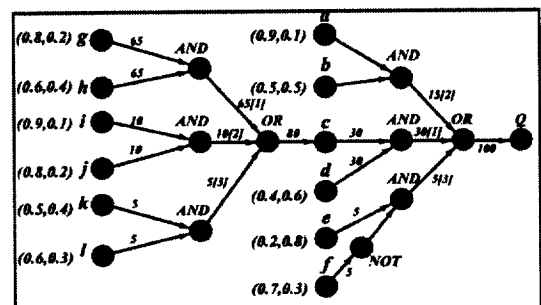
Fig. 18. Search by priority in Fuzzy Inference Network

priority in which priority are assigned to "OR" nodes to determine the belief value of node Q.

The belief values (α,β) given to proposition nodes in the fuzzy inference network can be varied dynamically by knowledge engineers. However, the priority given to connection links may be changed as the belief values of proposition nodes vary, because the priority is determined by search results which depend on the belief values of input nodes. Thus, the most appropriate search strategy is taken under a given environment, as the search is performed by dynamically adjustable search priority.

5. Experiments

The criteria for evaluation of experiments in this paper is IST (inference network search time for a node, unit: second) required to determine the belief value of a proposition node in the fuzzy inference network. Fig. 19 shows IST for sequential search and search by priority, as the number of rules in the fuzzy inference network increases.
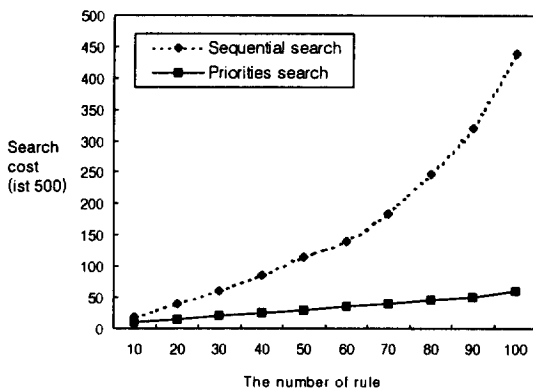
Fig. 19. Comparison of search cost according to the increase of number of rules.

The difference in IST between the two methods is larger as the number of rules increases. Therefore, search by priority is more efficient as the size of fuzzy inference network increases. [Fig. 20] compares IST for sequential search and search by
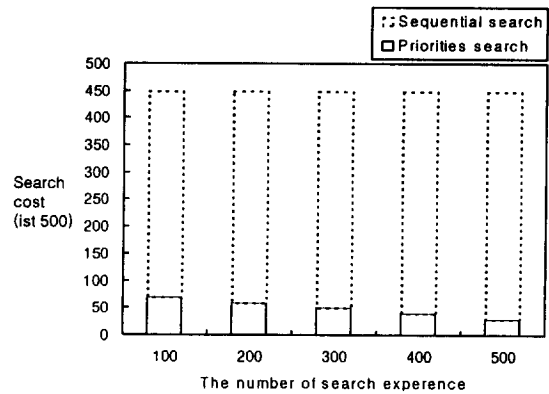
Fig. 20. Comparison of search cost according to the number of search experiences

priority as the number of search increases, when the number of rules is fixed as 100. While IST for sequential search is constant, IST for search by priority decreases as the number of search increases. This means that the efficiency of search by priority increases as the number of search increases. When the amount of knowledge consisting of a fuzzy inference network is large or when the knowledge database continuously expands through collection of knowledge, the IST may be an important factor for the performance of the entire system.

The experimental results in this chapter show that search by priority is more efficient than sequential search in the fuzzy inference network.

6. Conclusion

The fuzzy inference network is constructed by extending the concept of the existing inference network based on neural logic network. In the fuzzy inference network, the propositions consisting of fuzzy rules are represented using nodes. These nodes have belief value of each proposition.

The logical operators between propositions are represented using links. The traditional propagation rule is modified and applied in this paper.

Experiments are performed to compare search costs by sequential search and search by priority.

The experimental results show that the search by priority is more efficient than the sequential search as the size of the fuzzy inference network becomes larger and as the number of search increases.

The search by priority, however, depends on the previously-collected search experiences. Therefore, the fuzzy inference network needs to obtain some new search experiences to find out the most appropriate search paths, when it is modified. More studies on this feature will be performed in the future.

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